Norwegian University
of Life Sciences

Urban Wind Energy

The effect of obstacles and buildings

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Agenda

- Master thesis
- Blocking file feature
- Validation of WindSim
- Case study at Borg Havn
- Limitations and conclusion

Masters Thesis´s

- Motivation
- Urban wind energy
- Buildings and obstacles
- Validation
- Case study

"How do buildings affect the annual energy production for a wind turbine in an urban environment?"

Blocking File Feature

- Defined in a logical space
  - i- , j- and k-direction
  - No crossing lines
- Placement of obstacle
  - Cartesian coordinate system
- Distribution
  - Automatically generated in .bws-file
  - 1 corresponds to equal sized cells

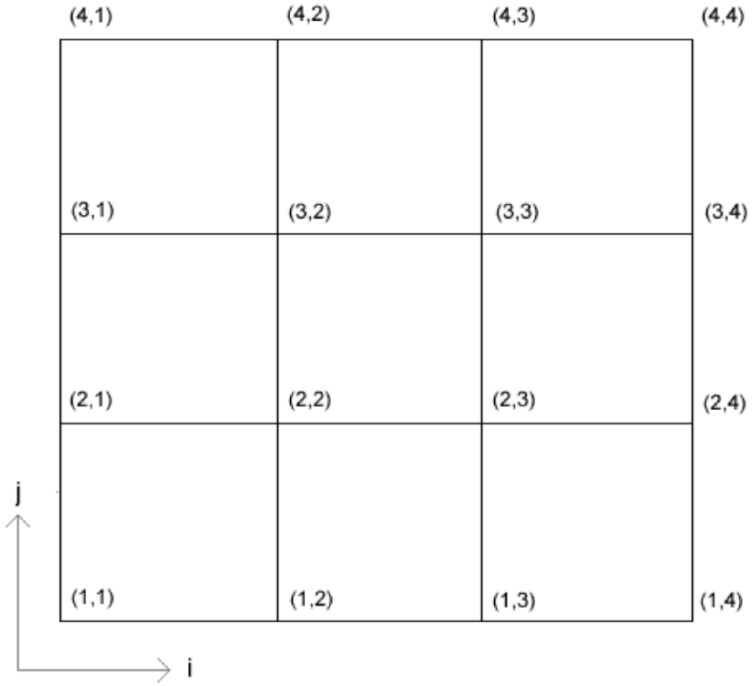


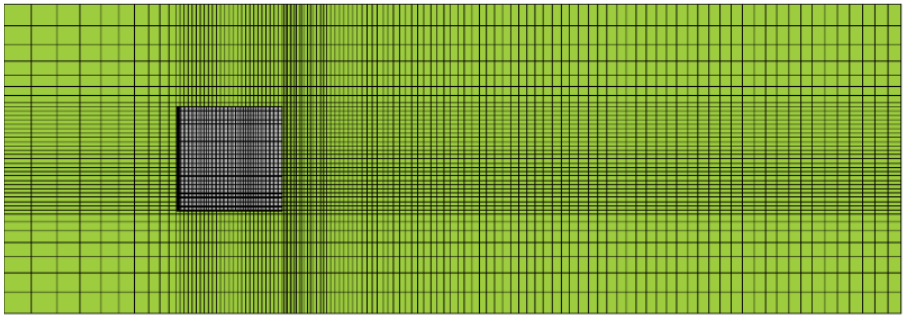
Figure 3.4: A logical space with grid at ground level, k=1 (WindSim, 2019)

Blocking File Example 1

- One obstacle
- i- and j-direction
  - 4 junction points
- k-direction
  - 3 junction points
- Distribution=1 at the obstacle
  - All directions

Blocking File Example 1

```
WindSim version    : 480

local_co-ordsys   :  type  x_trans  y_trans   angle

i-logical         :   line_i  points   distribution
                       1      14    8.5000
                       2      94    1.0000
                       3      14    0.1176

j-logical         :   line_j  points   distribution
                       1       7    5.0000
                       2      23    1.0000
                       3       7    0.2000

k-logical         :   line_k  points   distribution  z_upper
                       1       2    1.0000        0.1
                       2      19    0.1000        3.0

junctions         :      i     j     k  co-ord      x        y        z
                       1     1     1     3       0.0000     0.0000     0.0000
                       2     1     1     3       3.0000     0.0000     0.0000
                       3     1     1     3       7.0000     0.0000     0.0000
                       4     1     1     3      10.0000     0.0000     0.0000
                       1     2     1     3       0.0000     1.0000     0.0000
                       2     2     1     3       3.0000     1.0000     0.0000
                       3     2     1     3       7.0000     1.0000     0.0000
                       4     2     1     3      10.0000     1.0000     0.0000
                       1     3     1     3       0.0000     2.0000     0.0000
                       2     3     1     3       3.0000     2.0000     0.0000
                       3     3     1     3       7.0000     2.0000     0.0000
                       4     3     1     3      10.0000     2.0000     0.0000
                       1     4     1     3       0.0000     3.0000     0.0000
                       2     4     1     3       3.0000     3.0000     0.0000
                       3     4     1     3       7.0000     3.0000     0.0000
                       4     4     1     3      10.0000     3.0000     0.0000

junctions_obstacle :      i     j     k  co-ord      x        y        z

surfaces_obstacle  :     i_s   i_e   j_s   j_e   k_s   k_e   type

volumes_obstacle   :     i_s   i_e   j_s   j_e   k_s   k_e   kind    type    c1     c2    turb_sources
                         2     3     2     3     1     2   obstacle  0.0   0.000  0.000    false
```



Blocking file example 2

- Two blocks
- Different heights
- i- direction
  - Added 2 junction points
- j-direction
  - Same as in example 1
- k-direction
  - Added 1 junction point

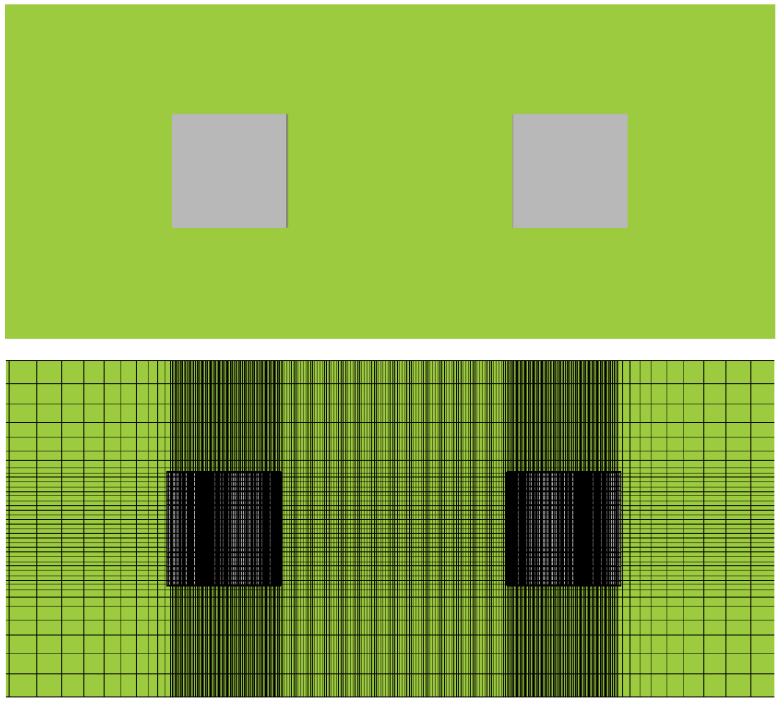
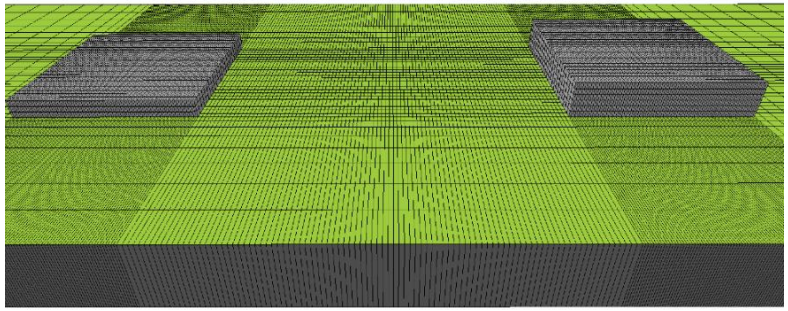


Figure 3.5: An example of two obstacles with corresponding refinement grid

Blocking file example 2

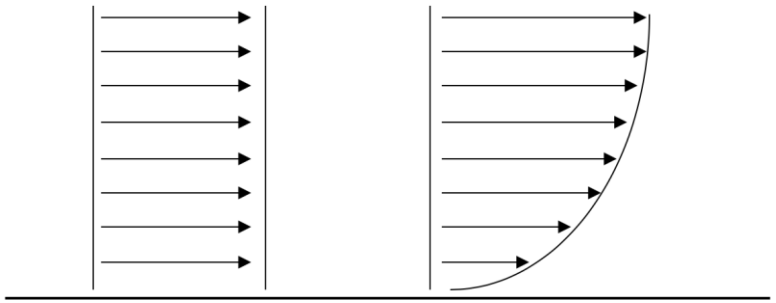
```
WindSim version    : 480

local_co-ordsys   : type  x_trans  y_trans   angle

i-logical         :  line_i  points   distribution
                      1      14    8.5000
                      2      94    1.0000
                      3      94    1.0000
                      4      94    1.0000
                      5      14    0.1176

j-logical         :  line_j  points   distribution
                      1       7    5.0000
                      2      23    1.0000
                      3       7    0.2000

k-logical         :  line_k  points   distribution  z_upper
                      1       2    1.0000        0.1
                      2       2    1.0000        0.2
                      3      19    0.1000        3.0
```

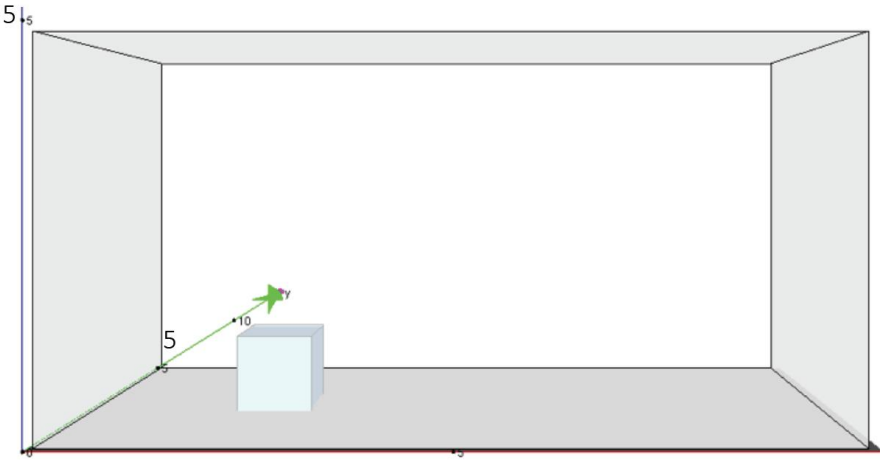
```
junctions       :     i     j     k  co-ord      x       y       z
                      1     1     1     3     0.0000     0.0000     0.0000
                      2     1     1     3     3.0000     0.0000     0.0000
                      3     1     1     3        4.0000     0.0000     0.0000
                      4     1     1     3     6.0000     0.0000     0.0000
                      5     1     1     3     7.0000     0.0000     0.0000
                      6     1     1     3    10.0000     0.0000     0.0000
                      1     2     1     3     0.0000     1.0000     0.0000
                      2     2     1     3     3.0000     1.0000     0.0000
                      3     2     1     3     4.0000     1.0000     0.0000
                      4     2     1     3     6.0000     1.0000     0.0000
                      5     2     1     3     7.0000     1.0000     0.0000
                      6     2     1     3    10.0000     1.0000     0.0000
                      1     3     1     3     0.0000     2.0000     0.0000
                      2     3     1     3     3.0000     2.0000     0.0000
                      3     3     1     3     4.0000     2.0000     0.0000
                      4     3     1     3     6.0000     2.0000     0.0000
                      5     3     1     3     7.0000     2.0000     0.0000
                      6     3     1     3    10.0000     2.0000     0.0000
                      1     4     1     3     0.0000     3.0000     0.0000
                      2     4     1     3     3.0000     3.0000     0.0000
                      3     4     1     3     4.0000     3.0000     0.0000
                      4     4     1     3     6.0000     3.0000     0.0000
                      5     4     1     3     7.0000     3.0000     0.0000
                      6     4     1     3    10.0000     3.0000     0.0000

junctions_obstacle :     i     j     k  co-ord      x       y       z

surfaces_obstacle :     i_s   i_e   j_s   j_e   k_s   k_e   type

volumes_obstacle  :     i_s   i_e   j_s   j_e   k_s   k_e   kind    type    c1     c2    turb_sources
                        2     3     2     3     1     2   obstacle  0.0    0.000  0.000    false
                        4     5     2     3     1     3   obstacle  0.0    0.000  0.000    false
```



Validation of WindSim

- Objective
  - Compare results with Castro(1977) and other studies
  - Study reattachment and recirculation
- Wind tunnel
- Uniform and logarithmic wind profile
- Perpendicular incidence angle





Obstacle and Grid Setup

Table 2: Blocking file setup

```
i-logical          :    line_i  points   distribution
                             1      20    7.4615
                             2      29    1.0000
                             3      40    0.1340

j-logical          :    line_j  points   distribution
                             1      20    5.8000
                             2      29    1.0000
                             3      20    0.1724

k-logical          :    line_k  points   distribution  z_upper
                             1      29    1.0000        1.0
                             2      30    0.1000        5.0

junctions          :         i       j       k  co-ord          x |           y           z
                             1       1       1       3        0.0000        0.0000        0.0000
                             2       1       1       3        2.0000        0.0000        0.0000
                             3       1       1       3        3.0000        0.0000        0.0000
                             4       1       1       3       10.0000        0.0000        0.0000
                             1       2       1       3        0.0000        2.0000        0.0000
                             2       2       1       3        2.0000        2.0000        0.0000
                             3       2       1       3        3.0000        2.0000        0.0000
                             4       2       1       3       10.0000        2.0000        0.0000
                             1       3       1       3        0.0000        3.0000        0.0000
                             2       3       1       3        2.0000        3.0000        0.0000
                             3       3       1       3        3.0000        3.0000        0.0000
                             4       3       1       3       10.0000        3.0000        0.0000
                             1       4       1       3        0.0000        5.0000        0.0000
                             2       4       1       3        2.0000        5.0000        0.0000
                             3       4       1       3        3.0000        5.0000        0.0000
                             4       4       1       3       10.0000        5.0000        0.0000

junctions_obstacle :         i       j       k  co-ord       x         y         z

surfaces_obstacle  :       i_s     i_e     j_s     j_e     k_s     k_e    type

volumes_obstacle   :       i_s     i_e     j_s     j_e     k_s     k_e    kind     type      c1      c2
                             2       3       2       3       1       2    obstacle  0.0     0.0     0.0
```

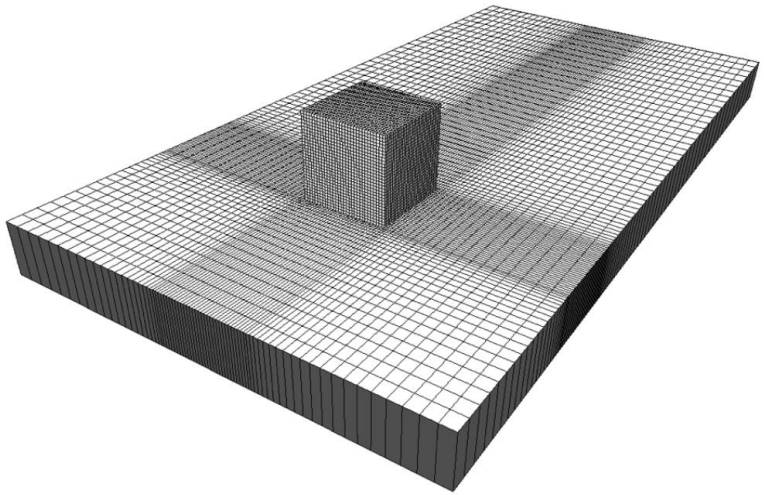


Figure 4.2: The grid with obstacle

Obstacle and Grid Setup

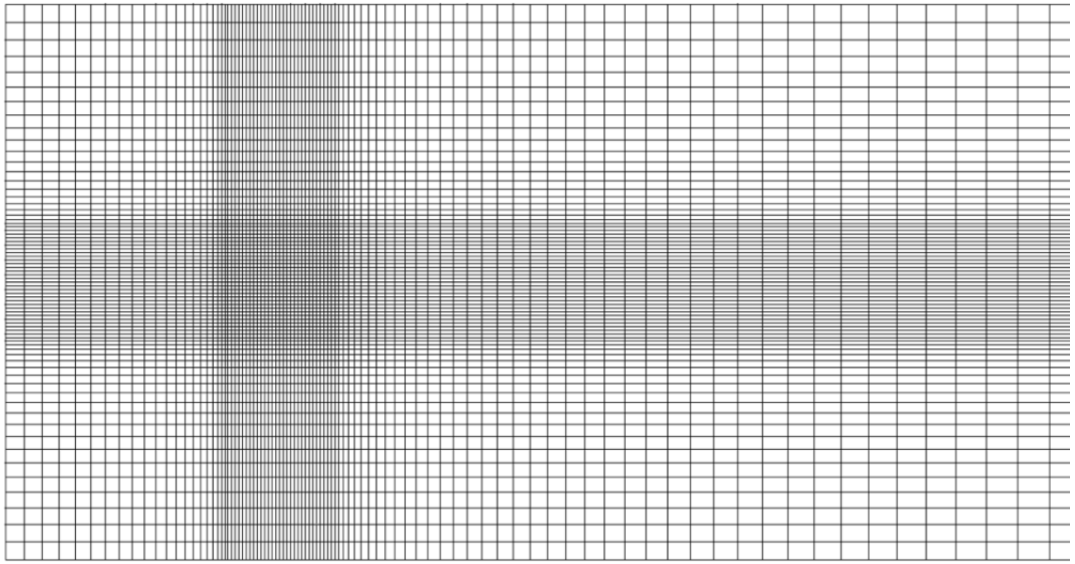


Figure 4.3: Grid in xy-direction

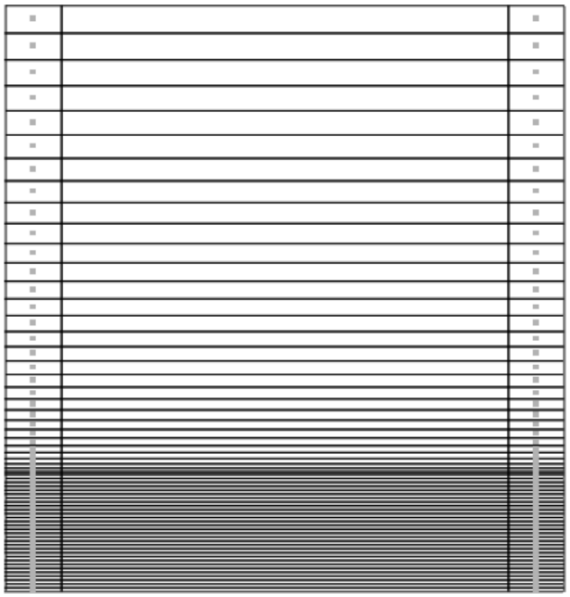


Figure 4.4: Grid in z-direction

Vertical Profile Extraction

- Two cases
- Extracted at different distances
- Compare with data from Castro(1977)

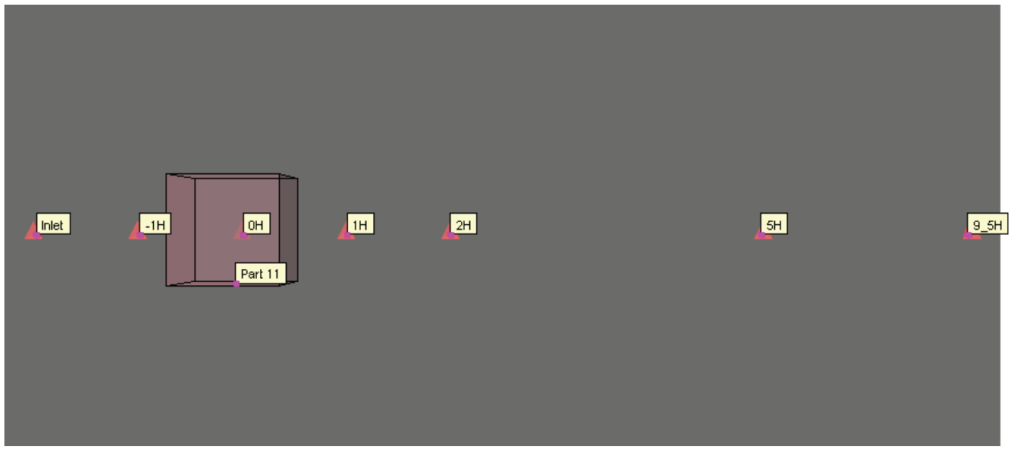


Figure 4.8: Measurement locations with corresponding distance related to the height of the obstacle

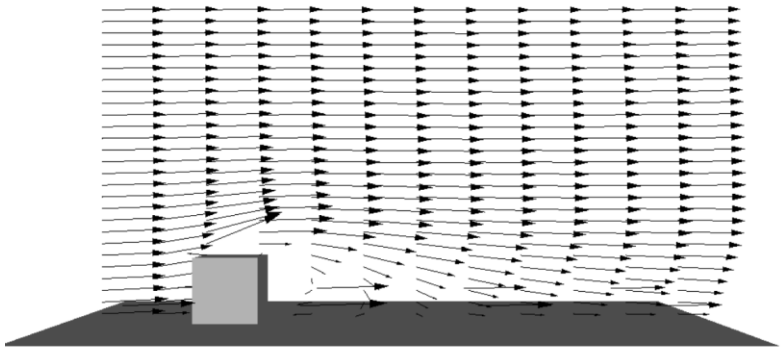


Figure 4.9: Uniform distributed wind profile (Case A)

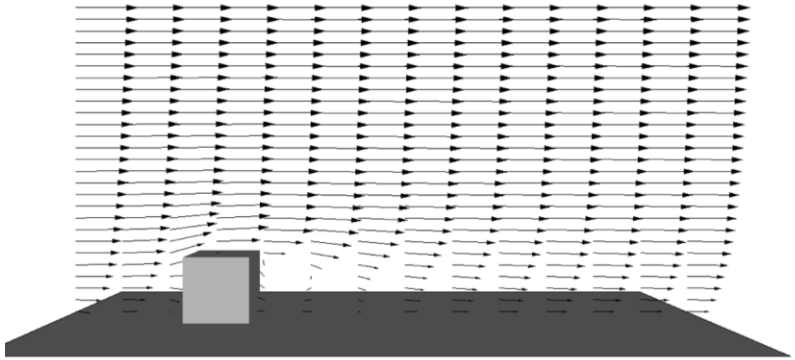


Figure 4.10: Logarithmic wind profile (Case B)

Vertical Profiles

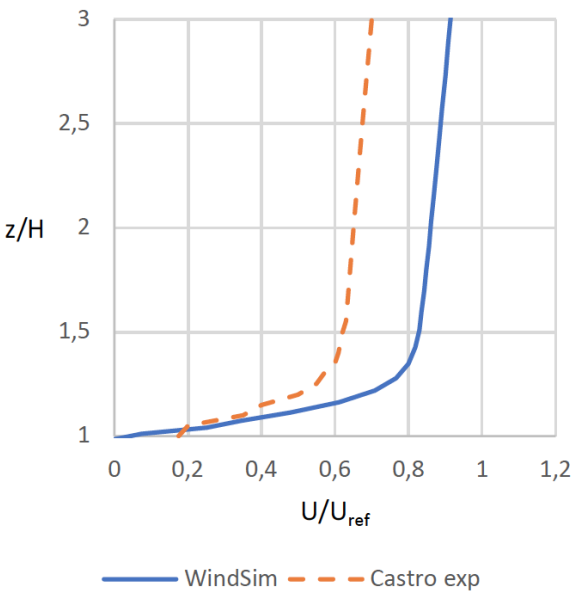


Figure 4.24: Case B at 0H

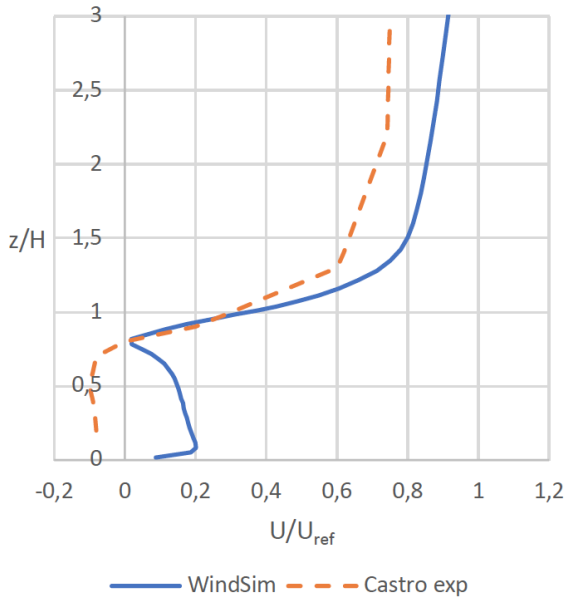


Figure 4.26: Case B at 1H

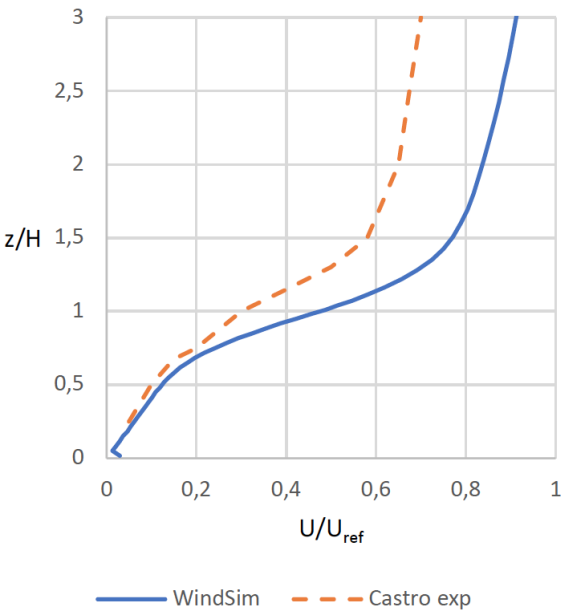


Figure 4.28: Case B at 2H

Vertical Profiles

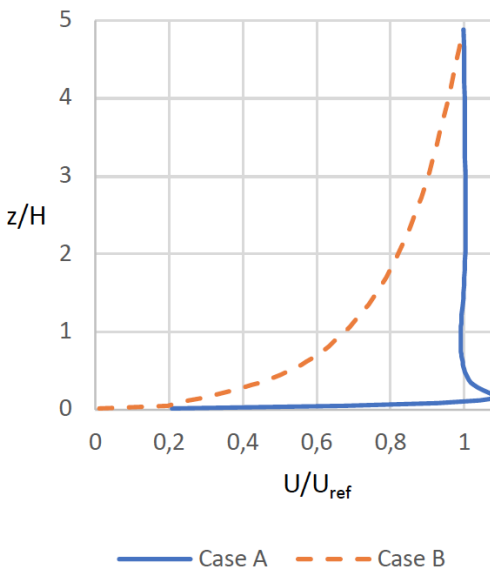


Figure 4.21: Inlet profiles of Case A and B

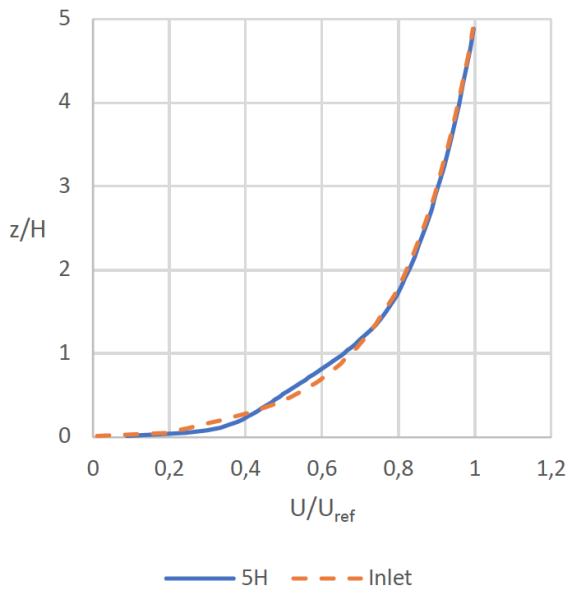


Figure 4.30: Case B comparison between the inlet and distance 5H

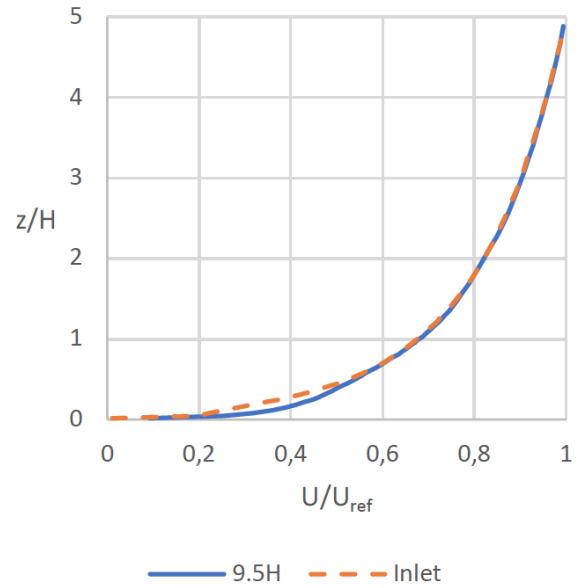


Figure 4.32: Case B comparison between the inlet and outlet at 9.5H

Cut Plane

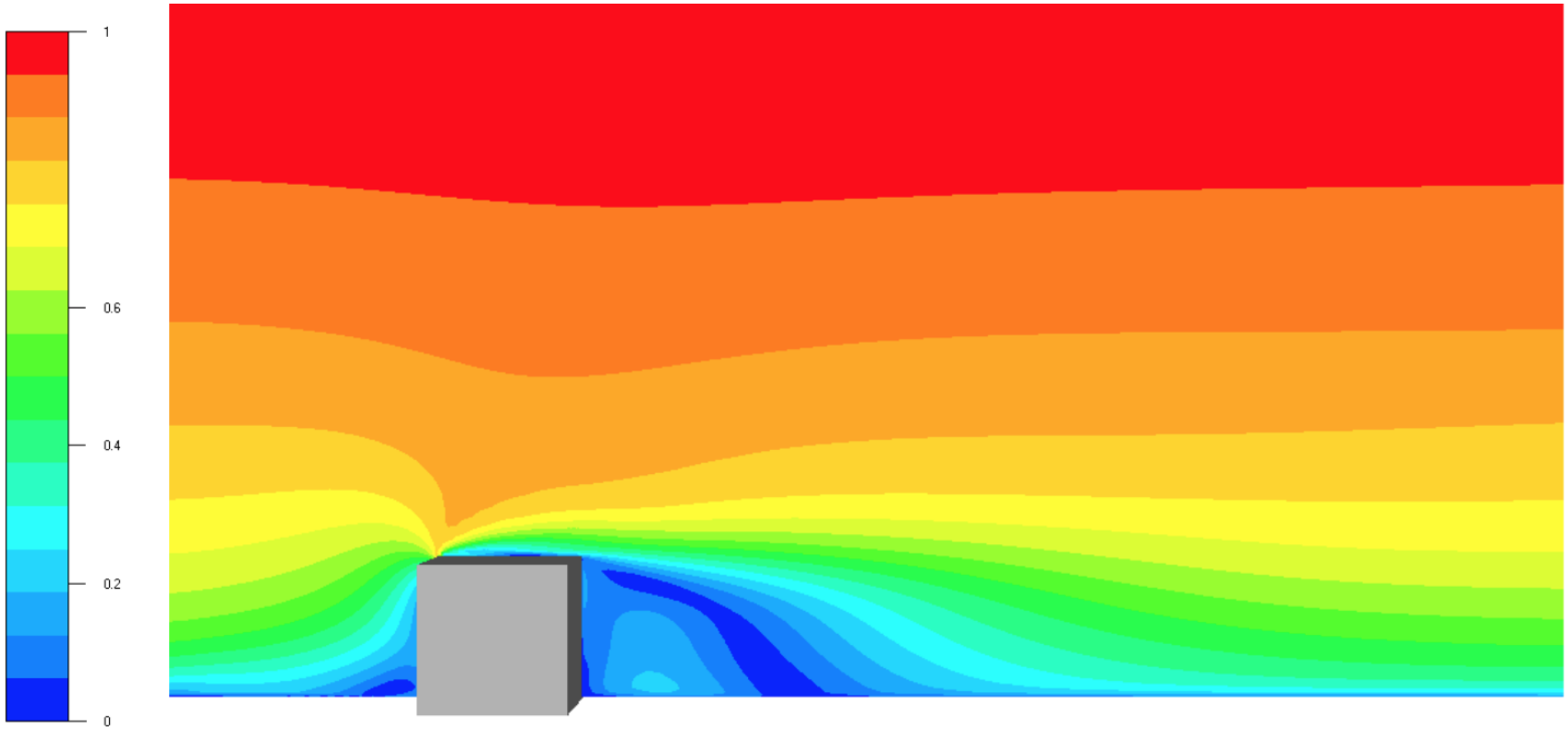


Figure 4.18: Vertical cut plane for xz-plane at y=0, legend in m/s

Vector Field

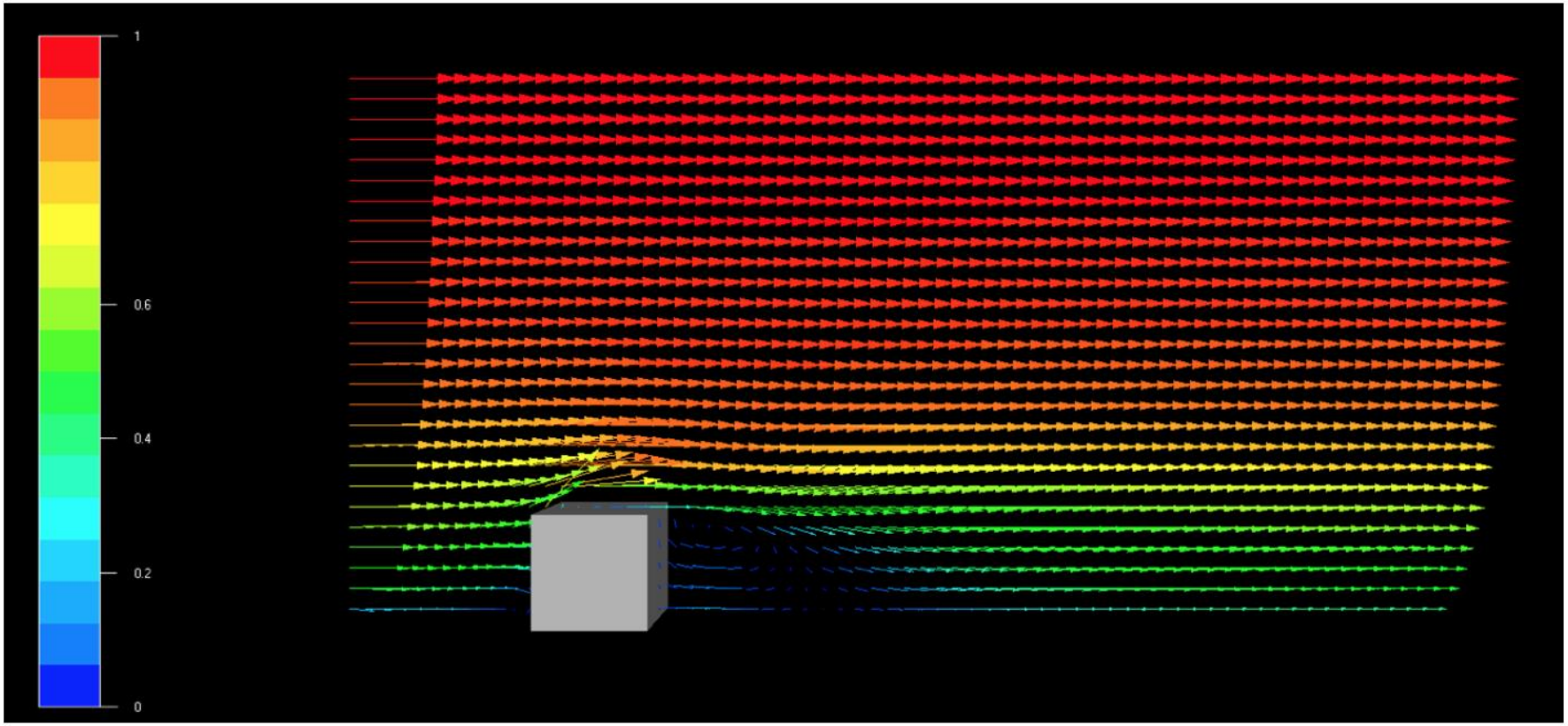


Figure 4.20: Vertical vector field at y=0 for 3D velocity, legend in m/s

Case Study: Borg Havn

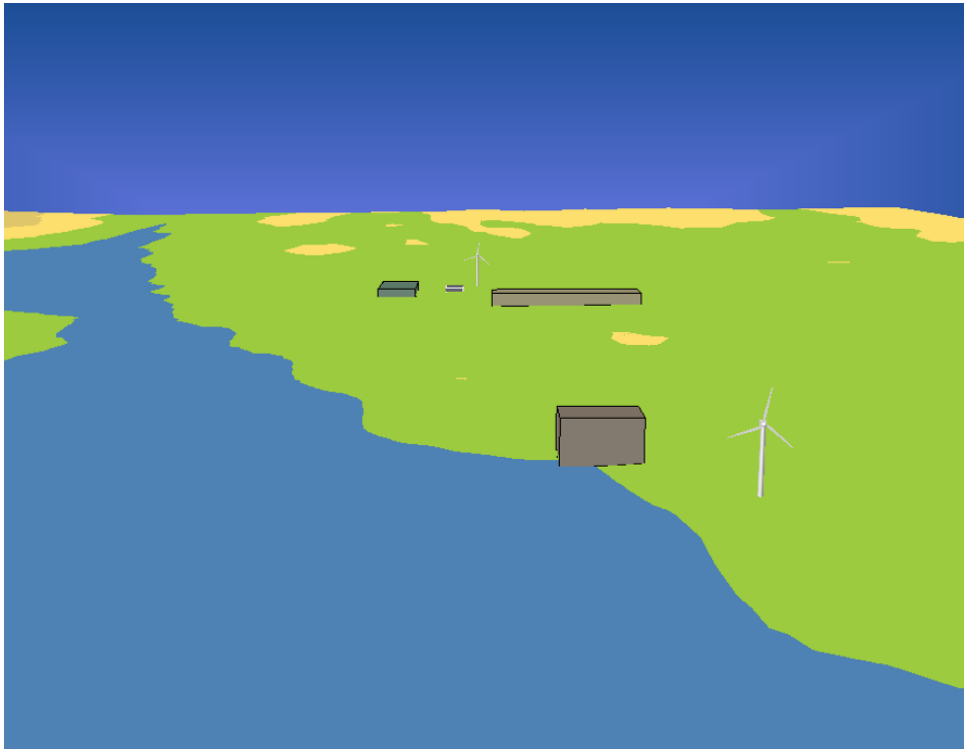
- WindSim
  - Established wind resources
  - Disregarded obstacles
- Goal
  - Utilization of self-produced green energy
- Objective
  - Investigate the effect of buildings at the port

Buildings and Wind Turbine

- 4 buildings
- Different heights
- Flat roofs
- Perpendicular orientation
- Vestas V39 1MW
  - Hub height 40 m

Table 7: Dimensions of buildings constructed at Borg Havn

Building	Length (m)	Width (m)	Height (m)
1	65	45	10
2	21	24	5
3	170	35	14
4	30	30	30



Grid and refinement setup

- Consists almost only of straight lines
- 8 junction points in i- direction
- 10 junction points j-direction
- 6 junction points in k-direction

Table 9: Values in z-direction with corresponding points, distribution and upper values

Line	Points	Distribution	Upper value (m)
1	9	1	5
2	9	1	10
3	9	1	14
4	9	1	30
5	9	0.1	800

Table 8: Blocking file used to create the grid and buildings

```
i-logical          :    line_i  points   distribution
                          1      19    30.0000
                          2      9     1.0000
                          3      9     1.0000
                          4      9     1.0000
                          5      9     1.0000
                          6      9     1.0000
                          7      14    0.0200

j-logical          :    line_j  points   distribution
                          1      19    30.000
                          2      9     1.0000
                          3      9     1.0000
                          4      9     1.0000
                          5      9     1.0000
                          6      9     1.0000
                          7      9     1.0000
                          8      9     1.0000
                          9      19    0.0100

k-logical          :    line_k  points   distribution  z_upper
                          1      9     1.0000        5.00
                          2      9     1.0000        10.0
                          3      9     1.0000        14.0
                          4      9     1.0000        30.0
                          5      9     0.1000        800.0

junctions          :         i       j       k  co-ord       x          y
                          1       1       1       3   610500.0000  6560354.
                          2       1       1       3   611803.0000  6560354.
                          3       1       1       3   611848.0000  6560354.
                          4       1       1       3   611883.0000  6560354.
                          5       1       1       3   611904.0000  6560354.
                          6       1       1       3   611973.0000  6560354.
                          7       1       1       3   612023.0000  6560354.
                          8       1       1       3   613000.0000  6560354.
                          1       2       1       3   610500.0000  6561454.
                          2       2       1       3   611803.0000  6561454.
                          3       2       1       3   611848.0000  6561454.
                          4       2       1       3   611883.0000  6561454.
                          5       2       1       3   611904.0000  6561454.
                          6       2       1       3   611973.0000  6561454.
                          7       2       1       3   612023.0000  6561454.
                          8       2       1       3   613000.0000  6561454.
                          1       3       1       3   610500.0000  6561484.
                          2       3       1       3   611803.0000  6561484.
                          3       3       1       3   611848.0000  6561484.
                          4       3       1       3   611883.0000  6561484.
                          5       3       1       3   611904.0000  6561484.
                          6       3       1       3   611973.0000  6561484.
                          7       3       1       3   612023.0000  6561484.
                          8       3       1       3   613000.0000  6561484.
                          1       4       1       3   610500.0000  6561779.
                          2       4       1       3   611803.0000  6561779.
                          3       4       1       3   611848.0000  6561779.
                          4       4       1       3   611883.0000  6561779.
                          5       4       1       3   611904.0000  6561779.
                          6       4       1       3   611973.0000  6561779.
                          7       4       1       3   612023.0000  6561779.
                          8       4       1       3   613000.0000  6561779.
                          1       5       1       3   610500.0000  6562074.
                          2       5       1       3   611803.0000  6562074.
                          3       5       1       3   611848.0000  6562074.
                          4       5       1       3   611883.0000  6562074.
                          5       5       1       3   611904.0000  6562074.
                          6       5       1       3   611939.0000  6562074.
                          7       5       1       3   612107.0000  6562074.
                          8       5       1       3   613000.0000  6562074.
                          1       6       1       3   610500.0000  6562109.
                          2       6       1       3   611803.0000  6562109.
                          3       6       1       3   611848.0000  6562109.
                          4       6       1       3   611883.0000  6562109.
                          5       6       1       3   611904.0000  6562109.
                          6       6       1       3   611939.0000  6562109.
                          7       6       1       3   612107.0000  6562109.
                          8       6       1       3   613000.0000  6562109.
                          1       7       1       3   610500.0000  6562144.
                          2       7       1       3   611803.0000  6562144.
                          3       7       1       3   611848.0000  6562144.
                          4       7       1       3   611883.0000  6562144.
                          5       7       1       3   611904.0000  6562144.
                          6       7       1       3   611939.0000  6562144.
                          7       7       1       3   612107.0000  6562144.
                          8       7       1       3   613000.0000  6562144.
                          1       8       1       3   610500.0000  6562190.
                          2       8       1       3   611803.0000  6562190.
                          3       8       1       3   611848.0000  6562190.
                          4       8       1       3   611883.0000  6562190.
                          5       8       1       3   611904.0000  6562190.
                          6       8       1       3   611939.0000  6562190.
                          7       8       1       3   612107.0000  6562190.
                          8       8       1       3   613000.0000  6562190.
                          1       9       1       3   610500.0000  6562209.
                          2       9       1       3   611803.0000  6562209.
                          3       9       1       3   611848.0000  6562209.
                          4       9       1       3   611883.0000  6562214.
                          5       9       1       3   611904.0000  6562214.
                          6       9       1       3   611939.0000  6562214.
                          7       9       1       3   612107.0000  6562214.
                          8       9       1       3   613000.0000  6562214.
                          1       10      1       3   610500.0000  6563700.
                          2       10      1       3   611803.0000  6563700.
                          3       10      1       3   611848.0000  6563700.
                          4       10      1       3   611883.0000  6563700.
                          5       10      1       3   611904.0000  6563700.
                          6       10      1       3   611939.0000  6563700.
                          7       10      1       3   612107.0000  6563700.
                          8       10      1       3   613000.0000  6563700.

junctions_obstacle :          i       j       k  co-ord       x          y

surfaces_obstacle  :       i_s     i_e     j_s     j_e     k_s     k_e    type

volumes_obstacle   :       i_s     i_e     j_s     j_e     k_s     k_e    kind
                           4       5       8       9       1       2    obsta
                           2       3       7       9       1       3    obsta
                           6       7       5       6       1       4    obsta
                           6       7       2       3       1       5    obsta
```

Grid and Refinement Setup

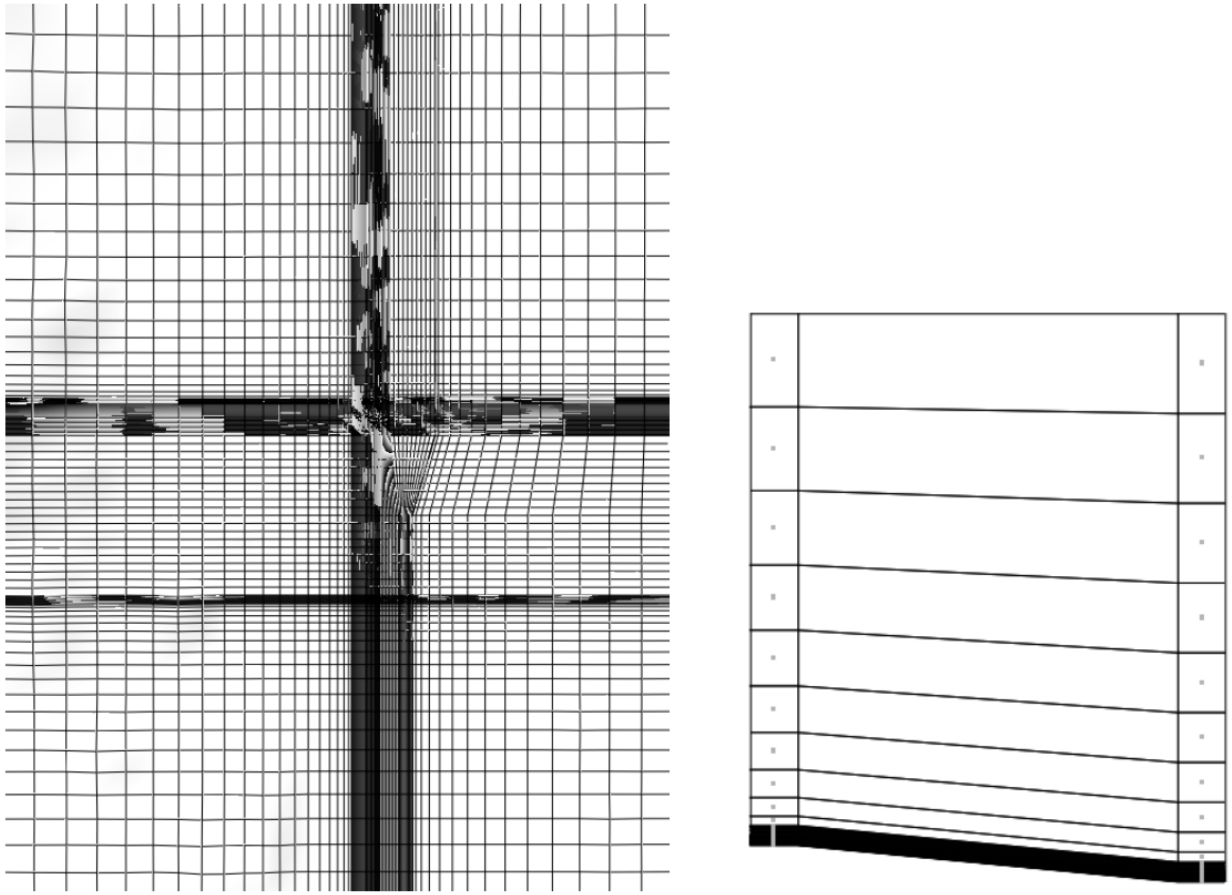
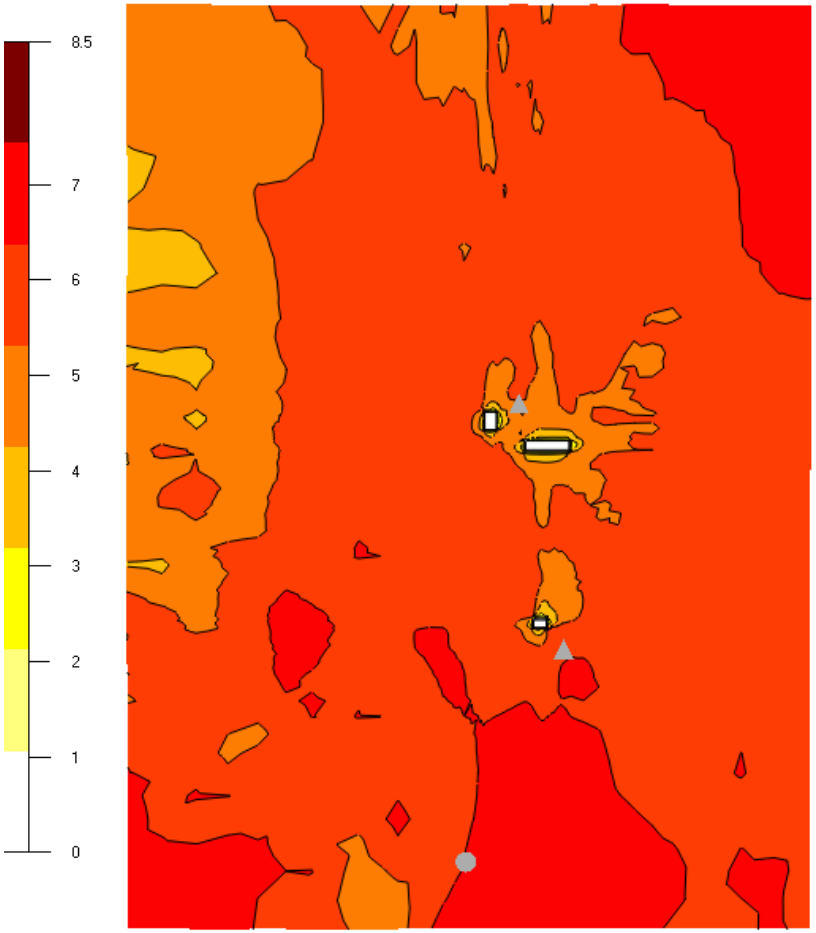
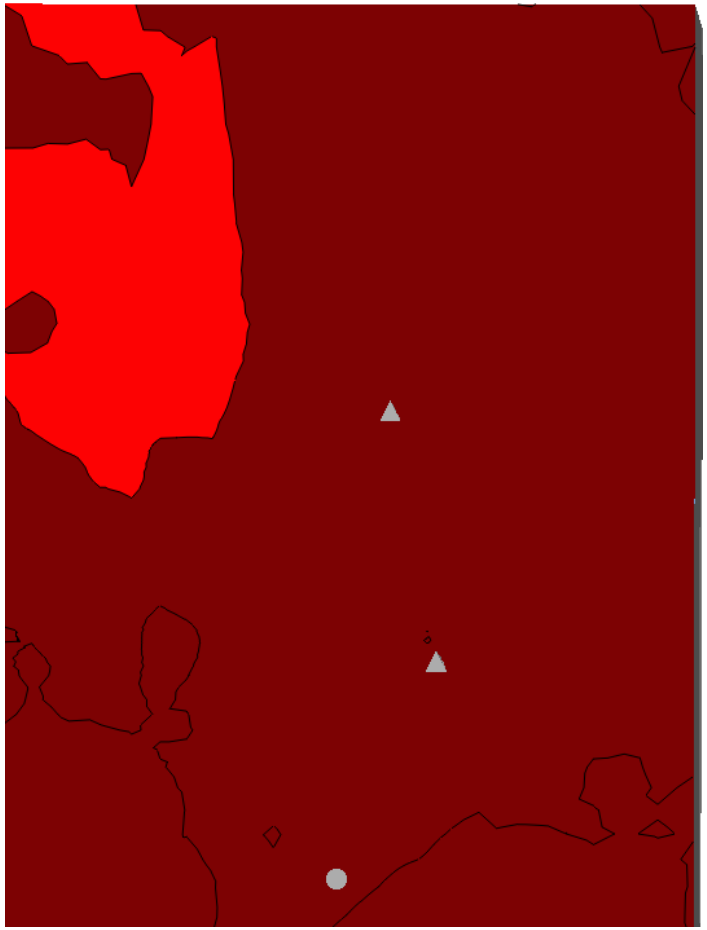


Figure 5.8: Grid in xy- and z-direction

Wind Resources



At 6m above ground



At hub height 40m

Cut Planes

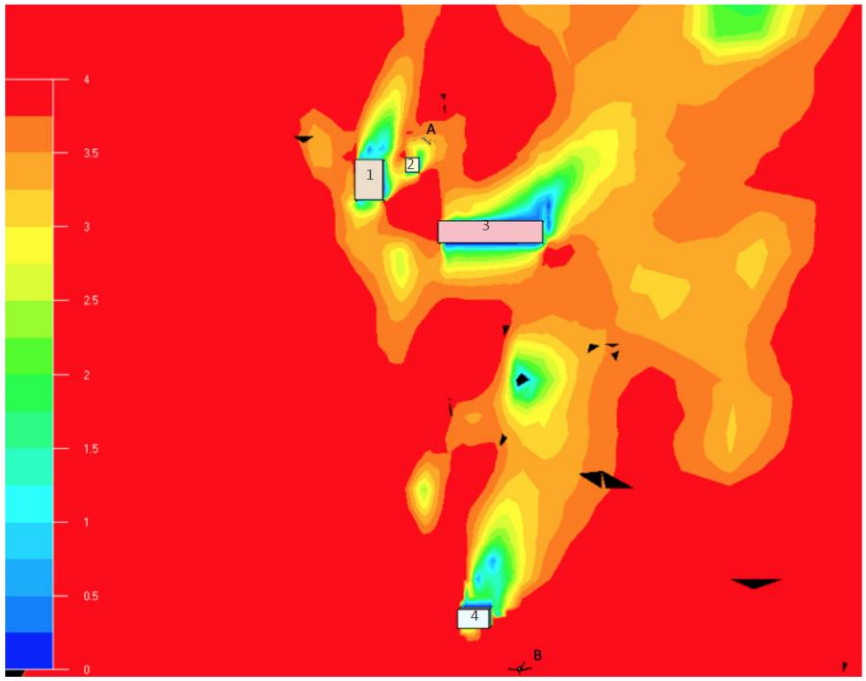


Figure 5.18: Cut-plane in xy-plane from 270° at height 6.5m

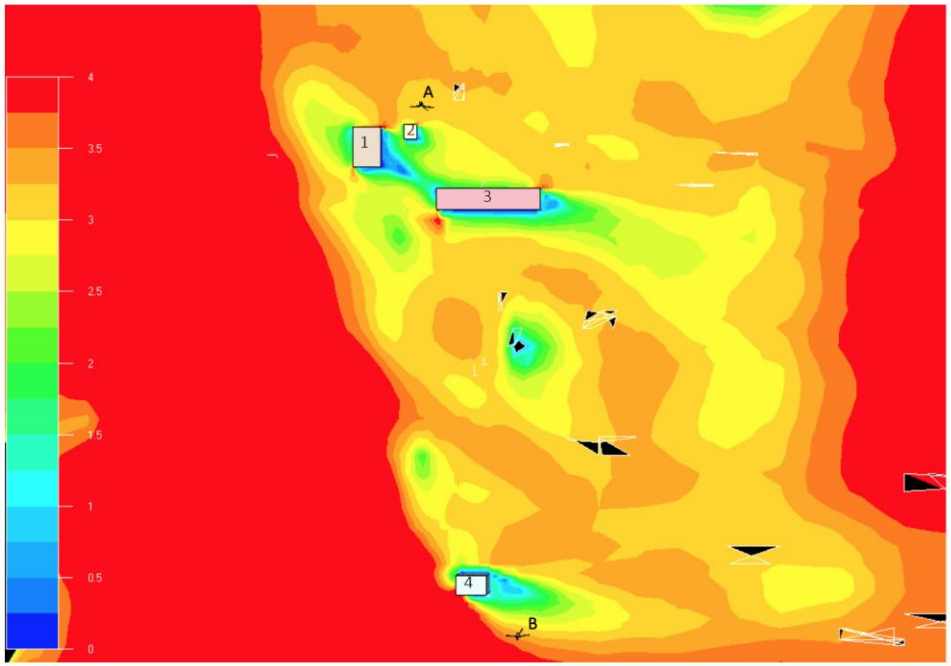
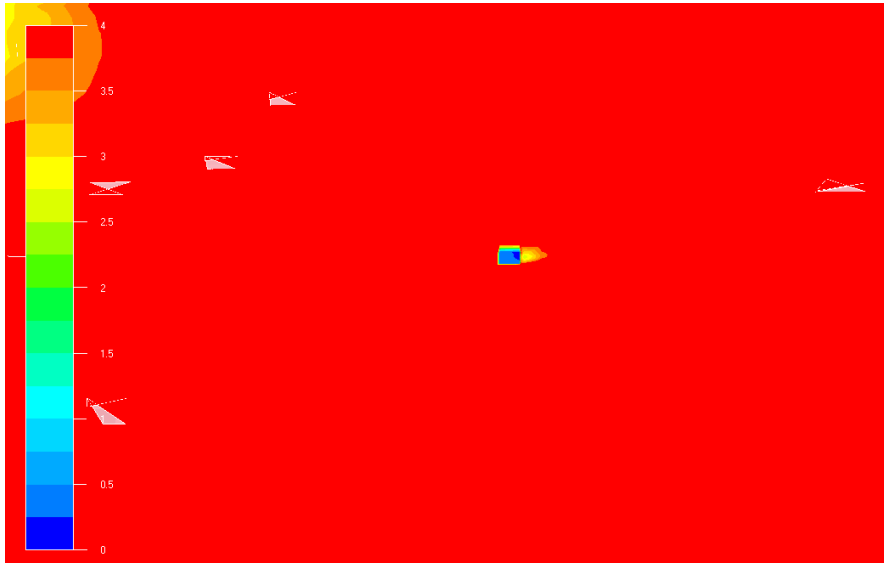


Figure 5.19: Cut-plane in xy-plane from incidence angle 330° at height 6.5m

Cut Planes



At 35m above ground

At 40m above ground

Annual Energy Production

Table 14: Total AEP with buildings

Turbine Type	Hub Height (m)	No. of turbines	Capacity (MW)	AEP (GWh/y)	Average wind speed (m/s)	Full load hours (hours)	Capacity factor (%)
V39	40.0	2	1.0	3.3	8.2	3322.7	37.9

Table 15: Total AEP without buildings

Turbine Type	Hub Height (m)	No. of turbines	Capacity (MW)	AEP (GWh/y)	Average wind speed (m/s)	Full load hours (hours)	Capacity factor (%)
V39	40.0	2	1.0	3.3	8.2	3327.3	38.0

Table 16: Total AEP per turbine with buildings

Turbine name	Turbine type	Average wind speed (m/s)	AEP (GWh/y)	Full load hours (hours)
Turbine A	V39	8.110	1.647	3294.600
Turbine B	V39	8.270	1.675	3350.800

Table 17: Total AEP per turbine without buildings

Turbine name	Turbine type	Average wind speed (m/s)	AEP (GWh/y)	Full load hours (hours)
Turbine A	V39	8.100	1.650	3299.000
Turbine B	V39	8.270	1.678	3355.600

Limitations

WindSim

- Validation
  - Old study, but much used
  - Incidence angle
- Setup
  - Grid independency
  - Number of cells

Case study

- Flat roof
- Correct orientation
- Climatology
- More buildings

Conclusions

WindSim

- Validation
  - Corresponds well
  - Negative wind speeds not produced
- Blocking file
  - Difficult to comprehend
  - Sufficient tool

Case study

- Buildings
- Effect
  - Buildings create wakes
  - No significant effect at hub height
- AEP
  - Small reductions

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Thank you!